THE PROGRESS OF METEOROLOGY.

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So LITTLE is generally known about the earliest beginnings of our present science of meteorology that a few words of historic *résumé* will probably not be unwelcome before I touch lightly upon some important features of its modern development.

We know from Biblical and other historic sources that atmospheric conditions have been observed from the earliest times, and attempts made at a rough characterization of the changes which have been noticed in wind and weather. Until the invention of the modern meteorological instruments of precision, all measures of meteorological conditions were made but indirectly, and cover at least whole seasons in their time extent. Such records as have come down to us in history refer to times of extreme cold or great floods; the opposite extremes of excessively hot seasons or great droughts are seldom explicitly mentioned, and we can only infer them from the accounts of famines which accompany them. There is one exception to this crudeness which deserves notice. It is probable that the direction of the wind has been noted with almost modern accuracy ever since the orientation which we now designate "points of compass" has been a recognized system. It has been estimated that the wind's direction was relegated to the four cardinal points of compass at least as early as 1000 B. C.; but it was not until about 500 B. C. that the Grecians added four additional directions. Probably the oldest arrangement which has come down to us for locating the direction of the wind is the "Tower of the Winds" at Athens; this dates from about 100 B. C.

The science of meteorology has been developed by the progress of civilization in Europe. It is therefore a distinctively European

science, and the story of its early growth can be studied only on the western continent. Climatology can be studied for Europe by somewhat rough methods for the period before the year 1000 A. D.; but we have very little data before that date, and even at that epoch we have only some records of very cold winters in some parts of Europe. The thermometer was invented by Galileo in the latter part of the sixteenth century, and we have a few records with this instrument extending back two hundred years or more. For about this same length of time there exists also a record of annual periods when the waters of northern Europe are ice-bound or free from ice. Likewise, in southern Europe, reliable records have been kept of the dates of grape harvest during the past four hundred years or more, and these dates are an index to the natures of the successive seasons.

Concerning rainfall we have still less satisfactory records. About all of the really old material that we have is the indirect measure of the rainfall shown by the fluctuation in height of the water level of some rivers or inland seas. There has been a much-broken record kept for the Caspian Sea since the tenth century; but the more reliable observations do not extend back more than two centuries, when the earlier continuous series of direct observations by means of rain-gauges were begun.

While some of the methods for measuring atmospheric moisture have long been known (since the fifteenth century), yet satisfactory records do not go back of the present century. Observations of atmospheric pressure by means of the barometer (invented by Torricelli in 1643) have been made with regularity for more than a century, but those records made before about 1825 have little claim to recognition by modern meteorologists on account of the unreliable instruments formerly used.

The improvement of instruments employed in meteorological work and the methods of using them have always received great attention from those engaged in this kind of work, but it has been only since about 1850 that anything like the modern conception of refined work has been adopted as a criterion of excellence. This last half of the century has witnessed the introduction of elaborately organized systems of meteorological services in nearly all of the civilized countries for the purpose of making climatic surveys; and this has necessitated the establishment of an immense number of more or less permanent observing stations which

have been equipped with instruments according to the kind of work which they are expected to accomplish. These stations vary in magnitude and importance from the thunderstorm station, where the voluntary lay observer employs no instruments at all except his timepiece, up to the elaborately equipped observatory manned by a permanent staff of half a dozen expert scientists; the observatories at Pawlowsk, Russia, and Potsdam, Germany, are the best examples of these last institutions, which unfortunately are known mostly by hearsay in the United States.

Formerly it was considered that almost any person could make meteorological observations with sufficient accuracy, but in reality a high order of skill is required; and it is certainly as difficult to read a thermometer to within a tenth of a degree as it is for an astronomer to observe the transit of a star with ordinary accuracy; or it is as hard to read a barometer to the nearest thousandth of an inch as it is to make a micrometer setting in measuring star distances.

The introduction of self-recording instruments for making meteorological observations opened a new era in the field of data-collecting. Activity in this line really began about 1850, but it has been only within the last twenty years that any extended application of this kind of apparatus has been made, and even now it is far less than is desirable. The best self-recording instruments furnish results of the same degree of accuracy as that obtained by a skillful observer by direct observations.

As a control for insuring the accuracy of observations, on an absolute scale, it has been found necessary to establish standards with which the instruments actually used in making the observations may be compared. Usually each country has had its own more or less thoroughly investigated and adjusted standards, and for international work it has been necessary to compare the standards of one country with those of another in order to allow for existing differences. It is probable, however, that it will be but a short time before the normal instruments of the International Bureau of Weights and Measures at Sèvres, Paris, will be adopted as the recognized standards throughout the whole world. This will give to our future meteorological observations a unity which they have not had heretofore.

The primary cause of collecting meteorological data was the determination of the normal conditions which prevail for any

place, and also the variations from these normals which the elements may undergo during the longer or shorter periods of change which are found to exist for each. There was, of course, almost from the first, more or less comparing of data for different places, but it required the genius of Humboldt to open up an immensely wider view of the subject by collecting together the scattered temperature observations, and drawing on geographical charts the lines of equal temperatures (isotherms). Ever since the appearance of these charts, in the early part of the century, it has been the ultimate object of most investigators who have devoted themselves to meteorology to reproduce such charts with greater completeness, and to show by a similar process the complete terrestrial distribution of other meteorological elements, such as air pressure, rainfall, wind force and direction, etc. As aids to the final completion of such a huge undertaking, nearly all of the civilized countries have published, and mostly during the past few years, tables and charts for the regions within their own boundaries; and in addition to this, many of the maritime nations have extended their inquiries to the high seas and uncivilized lands. It may be noted that the force of example has induced Japan to organize a meteorological service hardly inferior to those of Europe.

For clearness of expression the graphical presentation of meteorological data is much more advantageous than the representation by mere numbers; and this is especially true in all cases where geographical distribution is being considered. We find, therefore, a constantly increasing application of graphics to meteorology, not only in giving results in published form, but also as an aid in the process of investigation. There are, however, classes of analytical investigations where the expressions denoting magnitudes must be preserved in mathematical form in order that they may be systematically or symmetrically treated. Thus the average daily, hourly, or monthly normals and variations therefrom are still represented by the ordinary Bessel's Functions (the sine or cosine formula), although the use of this formula is now not nearly so frequent as was the case thirty years ago. The geographical distribution of averages for stations scattered over the whole globe can be well represented by the method of spherical functions which were applied by Gauss for terrestrial magnetism, by Schoch for air temperatures, and by Hill for gravity. This method, now so

little appreciated by meteorologists, will undoubtedly come into great favor in the near future.

The numerous methods of making and afterwards discussing observations gradually led to the idea that uniformity was a necessity if there was to be coöperation between the organized workers of various countries. About twenty years ago representatives from several different lands met at Leipzig to see what could be done to remedy the existing evils due to lack of system; and from this meeting resulted the international meteorological congresses which have met, since then, at intervals of about three years. These meetings have resulted not only in producing unity in the form of official meteorological publications issued by most civilized nations, but they have also brought about a thorough and much needed discussion of the relative merits of existing methods, and permitted concerted action to be taken in the matter of future work on an international basis.

In looking backwards over the extensive literature which has been produced concerning meteorology, I find two books which, more than others, furnish us with satisfactory reviews of the science up to the dates of their publication. These books are Kaemtz's *Lehrbuch der Meteorologie*, 1836, and Schmid's *Lehrbuch der Meteorologie*, 1860. We have no such works as these in either the English or French language. The progressive strides made in the subject since 1860, and especially within the past twenty years, have now rendered impossible any such recapitulative work in a single volume, or, indeed, by any individual author in a number of volumes. There are now, probably, a score of modern treatises on meteorology, by as many different authors, in which the main results of our progress have been brought before the reading or student public; but in nearly all of these cases selected topics have been treated to the exclusion of others of equal importance, but which could not be crowded into the pages of individual works. Thus we find even popular works specialized.

The subject of weather and weather predictions is the truly popular side of meteorology. It is popular with the people, and unfortunately it is still a "popular science" with those who view it professionally. From ancient times it has been the custom to make local weather predictions for the morrow from the aspects of the sky to-day; but the later phases of the question, the pre-

diction of weather for a distant locality, is of modern development. I can only make here a few references to the special topic of weather predictions in the middle latitudes. About the middle of the last century Franklin discovered that great storms moved across our country, from the west, in an easterly direction. But the storms moved with such rapidity that no practical use could be made of this discovery, in warning the people to the eastward of the approach of a storm, until a very rapid means of communication was established between the west and the east. This was furnished by the invention and introduction of the telegraph; but who first proposed the use of the telegraph for the purpose of sending storm warnings I am not quite certain. It is probable, however, that the idea occurred about the same time to persons in Europe and America, as soon as the practical success of telegraphy was demonstrated. The mere announcement of the existence of a storm to the westward, and that it might be expected in the east, did not satisfy the scientific mind. Loomis had invented a method of displaying on a map the weather conditions prevailing simultaneously at various observing stations scattered over the country (the eastern part of the United States); and, by means of lines of equal air-pressure and equal air-temperature, drawn on such a map, he laid bare the structure of our extended storms in such a manner that the true relations could be seen. Moreover, by drawing such maps for successive days, the gradual changes in the storm could be followed out, and the path of the storm could be accurately traced. Loomis did not investigate his storms until long after they had occurred, because he had to receive his data from the various sources by mail. The application of telegraphy, however, permitted the transmission at once from the various observing stations to a central point, where weather maps, according to Loomis's plan, could be made while the storm was still in progress; and then not only could the track already passed over by the storm be traced, but, judging from the previous courses of such storms, the probable future direction which it would take could be pointed out. Such is the general method of work pursued by our services for weather predictions at the present time, except that local phenomena are also taken into account in making predictions for any specially designated region.

The value of such work is as fully recognized in Europe as in our own country, and in fact the recent voluntary changes in our

American system of making weather forecasts have made it more than ever similar to the European method. Formerly our official weather predictions were mainly made at Washington, but now these are supplemented by the forecasts made by officials located at a number of points distributed over the country. In Europe each nation has its own weather predictors, and in order that each one may have a whole continental distribution of data at his disposal it is necessary to have a telegraphic exchange between the various countries.

Just a word can be added concerning the nature of these weather predictions. They are not, as some persons think, of a really satisfactory scientific nature. They certainly do require the application of certain faculties of judgment in order to make them successfully; but it has frequently been found to be the case that persons with a relatively very small amount of meteorological knowledge could make better predictions than the savants in the science. The progress in improving the methods of predictions has been very slight since their first beginning, and whatever gain has been made has been due to the increase of telegraphic and other facilities for the rapid transmission of data and the predictions themselves. Our weather maps have remained practically unchanged in form for years, and I venture to suggest that if the Weather Bureau would give us, for only one year, maps of the weather conditions two or three times a day, as shown by records from all of the State meteorological stations, as well as those from the present general government stations, we should have the means of studying the process of storm development with a much greater probability of adding to our present knowledge than is likely to occur without some such change in the plan now in use. In order to have storms so minutely portrayed as this would allow, we who are students would gladly wait for the maps a month or two as might be necessary. It is still too soon to hope that observations aloft may be made with regularity, but the missing links necessary for the true understanding of storms is undoubtedly to be found in the atmospheric conditions above the earth's surface. All long-range weather predictions are pure charlatanism, and any scientist who would have the temerity to foretell the weather conditions for a coming season, or even the coming week, would very deservedly lose caste with his fellow-workers.

The department of our science which deserves to stand highest in the esteem of men of thought is the so-called theoretical meteorology. This is the term now applied to the statics and dynamics of the atmosphere as developed in recent years by eminent physicists. It has been always considered that such variable phenomena as the winds could not possibly be governed by laws of sufficient simplicity for philosophers to detect them. It was perhaps the regularity of the trade winds which first suggested the possibility of system in the air movements. The greatest prominence is certainly given to them in the theory of the general circulation of the atmosphere as outlined by Hadley in his paper in the *Philosophical Transactions* in the year 1735. Hadley said that the difference in the temperature at the poles and the Equator gave rise to an ideal air circulation, which, being modified by the influence of the diurnal rotation of the earth on its axis, produced the existing general circulation. About a century later, Dove, the great German meteorologist, sought to extend Hadley's theory by following out further the action of the general currents, and assigning to their power and influence the origin of the secondary atmospheric disturbances which predominate in our latitudes and give us the winds of such proverbial variability. But Dove had not that breadth of conception which was necessary for solving the problem, and he became entangled in the details of his theory. And, moreover, his views so completely muddled the ideas of many of the students of his works that they have never yet been able, even at this late day, to see the value of subsequent theories. It remained for the philosophical mind of an American, William Ferrel, to point out some defects in earlier theories (especially in Hadley's) and lay before us a picture of the atmospheric circulation as a whole, and the relation to it of the secondary, aye and even the tertiary, systems of air movement. Ferrel's earlier papers were written in 1856-58-59, but he continued perfecting his grand theory in subsequent papers, and gives it to us as a whole in his book, *A Popular Treatise on the Winds.** This remarkable work should be read by every person who desires to know about the origin and maintenance of the greater and lesser air motions: it is to be regretted, however, that Ferrel did not present in this book the results obtained by other theoretical investigators in the same field of work. Ferrel's reasoning was mainly deductive

* John Wiley & Sons, New York, 1889.

and with one exception his work stands alone in the English meteorological literature of the present day. France has not produced any very great deductive meteorologist, but the Germans have taken up the matter with their usual thoroughness, and the works of Hann, Köppen, Sprung, Möller, Oberbeck, Werner Siemens, Von Bezold, and, last and greatest of all, Von Helmholtz have combined to form a literature of the greatest importance in the development of modern meteorology. In this same connection the work of the Norwegians Guldberg and Mohn must not be omitted, because they were the first of the continentalists to write, in 1876-80, an extended memoir on the subject of air motions, in which the subject is dealt with according to the modern mathematical methods of treating fluid motions.

I think that Ferrel's theory of the general circulation of the atmosphere will prove of far more lasting importance than his other work concerning the details of the secondary motions. These last in our latitudes are the huge cyclonic wind-whirls which sweep across our country in an eastwardly direction, and which, as we have seen, form our variable weather conditions. Theoretical meteorologists have sought to find the origin of these cyclones, and that of their opposites, the anti-cyclones, but it still remains a matter of doubt. Some investigators have considered them to be due entirely to local conditions of temperature and moisture; others have thought them to be caused by a combination of local conditions and the great primary hemispherical air circulation; while the studies of the eminent German physicists have led them to think that these huge vortical disturbances, often many hundred miles in diameter, are almost entirely due to the primary air circulation. This last is in some respects a return to the Dovian theory, but it is mainly in name, for the methods of investigation employed are entirely post-Dovian. In closing, I will add that the direct useful application of meteorology to commerce, navigation, agriculture, the practice of medicine, and hygiene is coming to be recognized as of such great importance that the hearty support is secured for it of persons who have the power to greatly promote its future growth.

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